

Estimating the sufficiency potential in buildings: the space between under-dimensioned and oversized

Anja Bierwirth
Wuppertal Institute for Climate, Environment and Energy
Doeppersberg 19
D-42103 Wuppertal
Germany
anja.bierwirth@wupperinst.org

Stefan Thomas
Wuppertal Institute for Climate, Environment and Energy
Doeppersberg 19
D-42103 Wuppertal
Germany
stefan.thomas@wupperinst.org

Keywords

energy sufficiency, residential buildings

Abstract

The emission reduction potential of energy efficiency and energy supply in buildings is estimated in various energy and climate action plans, scenarios, and potential analyses. But the third pillar of sustainability – sufficiency – is neglected in most studies.

The increasing demand of space per person in the residential sector is a trend in most European countries. Its implication on energy use, demand for resources like land, building material, equipment, and waste production is enormous. Next to the ecological impact, the distribution of space has social and societal effects. Thus, sufficiency policies in the building sector complementing efficiency and energy policy are needed for a sustainable development of the European building stock.

But how can a sufficiency potential in the building sector be estimated? How much space and equipment is needed for a decent living and how much is too much?

The paper proposes four areas of sufficiency in buildings: space, design and construction, equipment, and use. It presents a set of indicators, a quantitative estimate of energy savings from reduced per capita floor area, and visualises the sufficiency potential in European countries in an experimental approach. The final discussion focuses on the question: What does this mean for policy making?

Introduction

Sufficiency, though not a new concept, recently has become a more considered option to combat climate change as well as to reduce energy and resource consumption. Nevertheless, research in this field is still in its infancy. Scenarios, potential analyses, policy recommendations, and other studies in extremely few cases consider sufficiency (Zell-Ziegler and Förster 2018, Samadi et al. 2017; Schmitt et al 2015). However, the findings so far ascribe a notable potential to sufficiency, specifically energy sufficiency (négaWatt 2017; Fischer et al. 2016; Pfäffli 2012; Brischke et al. 2015a). Floor area per person in Europe in residential buildings is constantly increasing and the related energy consumption remains on a high level against all efficiency improvements in the buildings sector (Eurostat 2019 a). Reason enough to further elaborate the concept of sufficiency in buildings and its applicability in future research and policymaking.

In this context, the paper focuses on energy sufficiency in residential buildings. It begins with a brief explanation of sufficiency in buildings with respect to related concepts. This includes a derivation of a definition for ‘energy sufficiency in buildings’ and the location of sufficiency as a complementary strategy for efficiency (providing energy services more efficiently) and consistency (providing energy from renewable resources) including its overlaps. The paper then identifies areas for energy sufficiency in buildings and develops a set of indicators that shall help to estimate a saving potential. With a focus on the aspect ‘floor area per person’, it presents a first experimental approximation of an energy sufficiency potential. The final chapter discusses the results with a specific focus on policymaking and defines future research needs.

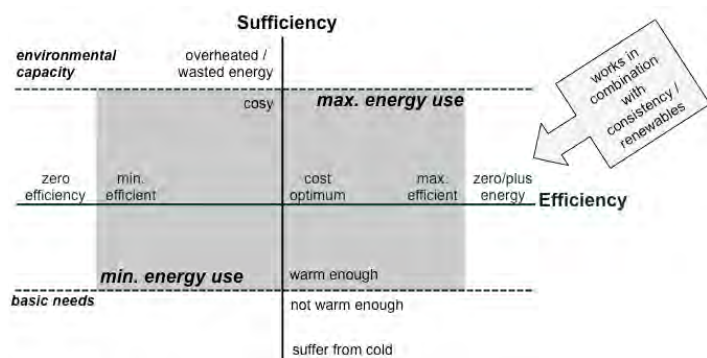


Figure 1. Interplay between energy sufficiency, efficiency and consistency defining limits and space for balancing efficiency and sufficiency. Source: Own illustration based on Bierwirth (2015).

Sufficiency as a concept and strategy

Sufficiency as a general concept or strategy has been defined and characterised in different ways. Brischke et al. (2015b) compile the discourse that reaches from “Voluntary Simplicity” (Elgin and Mitchell 1977) to the demand for “Politics for Sufficiency” (Schneidewind and Zahrndt 2013). Either way, the concept of sufficiency in general and energy sufficiency in particular¹ includes two aspects: an “outcome” (Thomas et al. 2015) or “state” (Darby and Fawcett 2018) and a type of “actions” (Thomas et al. 2015; 2018) that will move us towards this outcome.

ENERGY SUFFICIENCY AS A STATE

For the first Darby and Fawcett (2018) suggest the following definition:

Energy sufficiency is a state in which people’s basic needs for energy services are met equitably and ecological limits are respected.

Behind this definition stands the concept of the ‘Doughnut Economics’ (Raworth 2012) which in turn is based on the ‘Safe Operating Space for Humanity’ as part of the ‘Planetary Boundaries’ concept by Rockström et al. (2009) and earlier works (e.g. Meadows 1972). While the ecological limits – the ‘Planetary Boundaries’ – define the maximum, the social limits – people’s basic needs – determine the minimum. The area between both limits is ‘the safe and just space for humanity’.

Rockström et al (2009) show in a global perspective that some of the planetary boundaries are exceeded – Raworth (2012) uses the term ‘overshoot’. At the same time people’s basic needs are not met in various aspects (on a global scale: UN 2018), which Raworth (2012) calls ‘shortfall’. Consequently, it needs actions to minimise the ecological overshoot as well as social shortfall.

ENERGY SUFFICIENCY ACTIONS

Taking up on Darby and Fawcett (2018) the following definition for ‘energy sufficiency action’ is used for this paper as developed in Bierwirth and Thomas (tbp):

1. Sufficiency in general includes – next to energy related aspects – also other areas of demand and consumption, e.g. land use, food, water, etc.

Energy sufficiency actions are actions which reduce energy demand, to take us towards the energy sufficiency state, whilst at the same time changing the quantity or quality of the energy services demanded, in a sustainable way and not below people’s basic needs.

Meeting basic needs in this understanding is a precondition for energy sufficiency (e.g. having it warm enough in winter) which requires a minimum level of energy services. At the other end of the scale, energy sufficiency action avoids excessive demand of energy service levels (e.g. heating in winter with windows constantly open) to stay within ecological limits – the maximum level of energy demand that can be provided sustainably (see Figure 1).

DISTINGUISHING ENERGY SUFFICIENCY FROM EFFICIENCY AND CONSISTENCY

There is no existing clear and sharp distinction between the three strategies sufficiency, efficiency and consistency, and some actions show aspects of more than one strategy. For example, several publications use the term “energy-efficient behaviour” (e.g. Pyrko and Darby 2011), while many of the actions included are defined as “energy sufficiency actions” elsewhere (e.g. Thema 2015). However, for the focus of this paper, a certain overlap of the strategies is acceptable. Where necessary, the distinction will be specified.

To express the overall differentiation between energy efficiency, consistency, and energy sufficiency actions “changing the quality or quantity of the energy services” is of particular significance in the definition of sufficiency: efficiency reduces the energy demand but by definition leaves the level or quality of energy services unchanged. Neither do energy consistency actions, which focus on the substitution of non-renewable energy supply by renewable energies (e.g. Samadi et al. 2017). The quantity or quality of energy services can be changed by the user’s daily practices and routines (individual action) but also by providing different kinds of infrastructure or services (policy, business, or community action) (Thomas et al. 2018). Figure 1 illustrates the interplay between the three strategies with regard to energy demand for space heating.

ENERGY SUFFICIENCY IN BUILDINGS

So how can this concept of energy sufficiency be applied to buildings? Buildings are meant to provide room, security, usability, and a certain level of comfort. Over the lifecycle of buildings energy and resources are needed to build, equip, use, renovate, and finally deconstruct them. Each of these stages offer potential for energy sufficiency (including adjoining areas with rather indirect energy reduction effects like resources and material). But what exactly are these?

First, the dimension of a building and the floor plan, number, size, and height of rooms, the volume of a building, and its usable area influence the demand for heating, lighting, other appliances, and thus energy use. From a sufficiency perspective the question has to be answered: How many rooms does a building need, how large and high do rooms need to be? Thus, one area for energy sufficiency in buildings is **space**.

Second, the rooms and the building in general can be designed either for a very specific or rather flexible use. Figure 2 shows a simple example. This aspect is closely linked to

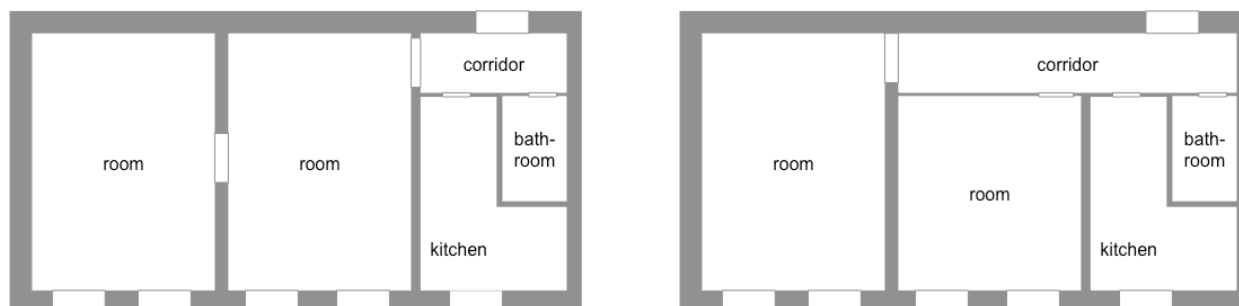


Figure 2. Floor plans with and without walk-through room. The flat with the walk-through room could be used by a single person or a couple furnishing a living room and a bedroom. But it is less suitable as a two-bedroom apartment e.g. for student co-housing than the flat with the two separate rooms. Source: Bierwirth and Thomas (tbp).

the construction that can allow or hinder easy adaptation of a building to changing needs and use, which may enable to reduce space per person.² This area encompasses **design and construction**.

Third, once the building is built it has to be equipped according to its use. Having residential buildings in mind, the questions for a energy sufficiency potential are: How many electric devices and appliances are needed? Are there possibilities to share single items?³ Thus, **equipment** is the third area for energy sufficiency in buildings.

Fourth, next to the performance, size of a building, and its equipment, it is the users' behaviour that determines energy use in buildings. Energy related behaviour and its potential for energy savings have been subject of many studies that shall be referred to at this point. It is relevant for the use of electricity as well as for heating (e.g. Delzendeh et al. 2017). So, the fourth area for energy sufficiency in buildings is **use**.

Following these four areas on the one hand and considering the limit of basic needs on the other hand, our working definition for the energy sufficiency state in buildings is *adequate space thoughtfully designed and constructed and sufficiently equipped for reasonable use*.

Delineating buildings along sufficiency aspects

With this definition it becomes clear that the planning phase is of particular importance to enable and exploit energy sufficiency potentials in buildings – which is also true for the efficiency standard and consistency aspects of a building (Delzendeh et al. 2017). The following table shows exemplary options for energy sufficiency in buildings in the four identified areas (Table 1).

2. The choice of single materials and building components determine the ecological footprint of a building as materials differ in their energy intensity (BMI 2017) while their connections (plug-in, screw, adhesive, etc.) offer a potential for reuse and recycling of components and materials (Doka 2000). As this aspect is closely linked to circular economy and resource efficiency and less to floor space reduction it is not elaborated further here.

3. Next to electric devices, these questions are also relevant for heating, cooling, and water heating equipment, e.g. featuring controls, such as night-time off or reduced temperatures, that enable energy-sufficient use. And even for furniture and décor: Is it possible to use second hand furniture to reduce energy consumption for their production?

How to assess energy sufficiency in buildings?

This list above could be extended but it is not about comprehensiveness at this point. Based on these concrete examples the next step is to identify related indicators to make the sufficiency potential in the four areas assessable.

ENERGY SUFFICIENCY INDICATORS IN BUILDINGS

Table 2⁴ compiles such a set of indicators. With regard to the definition of energy sufficiency in buildings, the indicators shall allow an assessment of the energy saving potential from energy sufficiency but also of the compliance with basic needs.

To work with these indicators, the according data has to be available. The column “Data available” here refers to European statistics and shows that a full assessment of an energy sufficiency potential at European level is not possible to date. Therefore, in the following the paper focuses on the area of ‘space’ and more specifically on the floor area per person as the area with best available data.

DEFINING BENCHMARKS FOR ENERGY SUFFICIENCY IN BUILDINGS

To quantify an energy saving potential, the minimum and maximum limits of the indicators above have to be discussed. With a focus on ‘space’ and referring to the definition for energy sufficiency in buildings above, the question arises: How much floor area is ‘adequate’ and how much is ‘too much’? This is a sensitive and very individual point, in which answers can differ widely from person to person. Thus, an important aspect of ‘meeting basic needs’ is the satisfaction of people with their housing condition. As data on European level assesses the overall satisfaction but not with respect to the size of dwellings, this aspect cannot be integrated to date. But it can be stated “... that people’s perception of internal space is only loosely correlated to the actual amount of internal space” (Morgan and Cruickshank 2014).

As data on floor area per person present average numbers, a benchmark for e.g. floor area per person is not meant as an individual target. With some people living below and others above this benchmark it still can be reached. Having a look at

4. Overall satisfaction with housing conditions: https://ec.europa.eu/eurostat/statistics-explained/index.php/People_in_the_EU_-_statistics_on_housing_conditions#Lack_of_satisfaction

Table 1. Exemplary options for energy sufficiency in buildings in the four areas space, design & construction, equipment, and use.

Space	
Smaller buildings/flats	New built houses usually offer more floor area than by number of rooms' comparable buildings of earlier ages. The average size of rooms partly can be reduced without loss of comfort and rooms can be used flexibly (e.g. home office/guest room, kitchen-diner). Commonly used rooms can reduce the demand for individual use.
Optimising use of room and space	The use of under-occupied existing buildings and flats can be optimised by subleasing or dividing a house/flat into two units. Avoided vacancies can reduce the need for new built homes. High ceilings can be used for built-in elements like loft beds, storage, etc.
Design & Construction	
Flexibility of floor area	Housing concepts can provide flexibility in the size of flats offering rooms that can be connected and disconnected in accordance to the size of a household.
Deconstruction instead of demolition	Construction can allow optimised dismantling of single building components supporting their reuse (e.g. windows, doors, curtain walls, etc.) The connection of two materials (e.g. brick wall to insulation) affects the purity of material and thus the possibility for reuse and recycling (e.g. adhesive connections vs. screwed connection).
Equipment	
Reduced number of appliances	The number of appliance can be reduced by common use (e.g. common room with washing machines instead of washing machines in all dwellings of a building, co-working spaces with computer, printer and other technical equipment).
Heating, Cooling, Airing, Lighting	Heating, cooling and airing is closely linked to the efficiency of a building. The heating, cooling and/or airing system should be adapted to the efficiency level (e.g. energetic retrofit of a building's envelope might lead to an oversized heating system). Lighting is not only a question of efficiency and the use of LED but also a question of how many light spots are needed for adequate brightness.
Use	
Reduce heating energy use	Choosing a lower room temperature and keeping windows closed while heating.
Reduce electricity use	Using appliances and equipment only when needed, switching lights off when leaving a room, avoid stand-by, sharing appliances (e.g. washing machines), purchase only equipment needed, use non-electronic alternatives (e.g. juicer).

Source: Own illustration based on Bierwirth and Thomas *tbp*.

the floor area per person in European countries, it is striking that it increases in almost all countries – except from Luxembourg which is on a high level already (see Table 3). The difference between 18 m² per person in Romania and 63 m² per person in Portugal and Denmark is remarkable and even more implies the question what is adequate.

As stated above sufficiency to date hardly plays any role in energy and climate scenarios and studies, especially not regarding buildings and floor space per person (Zell-Ziegler and Förster 2018; Samadi et al. 2017). There are few exceptions from France (négaWatt 2017), Switzerland (Pfäffli 2012), and Germany (Thomas et al. 2018; Günther et al. 2017). While most scenarios calculate with a further increase of floor area per person, the French and German studies estimate a stabilisation on a high level or a slight decrease. The study by Pfäffli (2012) instead assesses the energy saving potential of an average floor area of 30 m² instead of 45 m². So, is 30 m² per person a benchmark for sufficiency of floor area?

Another approach is to take a look into German regulation that defines an 'adequate floor area' for households receiving housing allowances: In North Rhine-Westphalia it is 50 m² living space for a single person, 65 m² for a household with two persons, and additional 15 m² for each other person, plus kitchen (15 m²) and secondary rooms (IM NRW 2019).

Table 4⁵ shows the average floor area per person in Germany under these conditions: it would be 32.3 m² for the year 2015 instead of 46.2 m².

ENERGY SAVING POTENTIAL FROM FLOOR AREA REDUCTION

Taking the approaches above as reference value the benchmark for 'adequate' space is set between 30 m² and 35 m² in the following experimental estimation of an energy saving potential. Experimental in that way, as to date it is not foreseeable that the trend of an increasing floor area per person will reverse. However, we assume the countries above the benchmark will lower their floor area per capita and those below will increase it.

As a simplified assumption, the relative reduction of floor space is transferred into energy savings for space heating in residential buildings. Simplified therefore, as energy consumption and savings are not necessarily related one to one to the floor space used. This is even more true for the use of electricity, thus the calculation focuses on space heating in Table 5. However, the aim of this experiment is a first approximation and

5. Households with more than five members are considered by calculating with 5.8 persons per household which in sum corresponds to a total population of 82.18 million in Germany 2015 (Destatis 2019).

Table 2. Indicators for an energy sufficiency assessment in buildings at European level.

Area	Indicator	Unit of measurement	Data available
Space	floor area per person	m ² /cap	Yes
	rooms per person	room/cap	Yes
	size of dwellings	m ² /dwelling	Yes
	height of ceilings/volume	m ³ /dwelling or building	No
	rate of overcrowded and under-occupied dwellings	% of dwellings	yes
	time a building, dwelling, or room is used	h/day or days/month	No
	vacancies of dwellings and buildings	% of dwellings	yes
	lack of sanitary facilities (bath, shower, flushing toilet)	% of population	yes
	satisfaction with size of dwelling	% of population	no*
Design & construction	flexible size and organisation of rooms	yes/no	No
	multiple usable rooms/areas	yes/no	No
	flexibility of construction for adaptation of floor plan	yes/no	No
	construction allows decomposition instead of demolition	yes/no	No
	reuse rate of building components and materials	% of material	partly
	leaks in roof, damp walls, rotten windows, etc.	% of population	yes
Equipment	heating/cooling system adequate for size and performance of building (kWh final energy/h of full-load hours) and enabling reasonable use	yes/no	No
	dwelling comfortably warm in winter	% of population	yes
	lack of appliances for supply work	% of population	No
	appliances for common use	appliances/household	partly
Use	indoor temperature levels	°C	No
	windows closed while heating or cooling	yes/no	No
	shock ventilation (short-term wide window-opening instead of long-term tilting)	yes/no	No
	room by room, daytime/night-time temperature control	yes/no	No
	energy use for heating per person	kWh/cap	yes

Source: Own illustration based on Bierwirth and Thomas *ibp*.

Table 3. Floor area per person in residential buildings in European countries 2008 and 2014.

Country	2008	2014	Country	2008	2014
Romania	15.58	17.99	Germany	42.10	46.87
Poland	24.22	27.05	France	45.61	47.24
Lithuania	25.60	29.53	Sweden	49.22	49.05
Estonia	29.36	31.44	Italy	48.95	49.14
Slovakia	30.48	31.67	Luxembourg	52.69	52.34
Croatia	31.39	38.23	Spain	49.72	52.33
Latvia	28.57	34.30	Netherlands	48.42	52.66
Slovenia	33.19	34.61	Finland	50.73	52.82
Czech Republic	34.05	35.70	Greece	50.80	53.44
Belgium	38.06	38.70	Austria	48.50	52.57
UK	40.08	42.37	Malta	43.79	62.81
Ireland	40.62	45.75	Denmark	–	63.10
Hungary	38.26	45.61	Portugal	51.52	63.39
Bulgaria	32.02	45.83	Cyprus	72.08	77.59

Remark: Data has to be considered against a high share of holiday homes and tourist apartments in some regions that might lead to a bias in the actual floor space. Source: Eurostat (2018), EU Building Database.

Table 4. Theoretical average adequate floor space per capita in Germany 2015 based on a particular definition of 'adequate space'.

Size of household	Adequate size	m ² /cap	Share of households	Number of persons	Total m ²	Average m ² / person
1 person	50	50.0	41.4 %	16,834,560	847,872,000	
2 persons	65	32.5	34.2 %	28,016,640	910,540,800	
3 persons	80	26.7	12.1 %	14,868,480	396,492,800	
4 persons	95	23.8	9.0 %	14,745,600	350,208,000	
5 persons +	110	22.0	3.2 %	7,588,282	151,765,647	
Sum				82,176,442	2,656,879,247	32.3
Actual floor area 2015					3,794,976,000	46.2
Difference					1.138.096.753	13.9

Source: Own calculation based on IM NRW 2019 and Destatis 2019.

Table 5. Theoretical energy savings potential (TJ) in EU countries by lowering average floor space per person to 30 and 35 m²/cap. Negative numbers mean an increase of floor space/energy use.

Country	Current m ² /cap	Reduction to 35 m ² /cap	Reduction to 30 m ² /cap	Energy use space heating	Energy savings space heating	
					35 m ² /cap	30 m ² /cap
Belgium	38.2	8.3 %	21.4 %	– (no data)	–	–
Bulgaria	46.1	24.1 %	34.9 %	48,892	11,777	17,079
Czech Rep.	35.6	1.7 %	15.8 %	188,586	3,261	29,736
Denmark	62.7	44.2 %	52.2 %	108,654	48,037	56,696
Germany	46.6	24.9 %	35.7 %	1,518,242	378,547	541,361
Estonia	31.5	-11.2 %	4.7 %	–	–	–
Ireland	45.5	23.1 %	34.1 %	69,256	16,016	23,622
Greece	53.8	34.9 %	44.2 %	114,045	39,819	50,422
Spain	52.4	33.2 %	42.7 %	275,292	91,403	117,673
France	46.9	25.3 %	36.0 %	1,020,262	258,128	367,004
Croatia	33.0	-6.1 %	9.1 %	69,147	-4,191	6,286
Italy	49.1	28.8 %	38.9 %	931,928	267,987	362,836
Cyprus	59.0	40.7 %	49.2 %	–	–	–
Latvia	34.6	-1.3 %	13.2 %	29,671	-373	3,919
Lithuania	29.8	-17.6 %	-0.8 %	40,564	-7,157	-340
Luxembourg	51.1	31.5 %	41.3 %	16,151	5,090	6,670
Hungary	45.7	23.4 %	34.4 %	182,798	42,825	62,821
Malta	62.2	43.8 %	51.8 %	537	235	278
Netherlands	52.4	33.3 %	42.8 %	252,488	83,964	108,039
Austria	55.0	36.4 %	45.5 %	172,950	62,891	78,613
Poland	27.1	-29.3 %	-10.9 %	510,423	-149,784	-55,468
Portugal	63.7	45.1 %	52.9 %	22,745	10,249	12,034
Romania	18.1	-93.8 %	-66.1 %	204,106	-191,508	-134,992
Slovenia	34.6	-1.2 %	13.2 %	30,371	-371	4,021
Slovakia	31.6	-10.6 %	5.2 %	–	–	–
Finland	52.6	33.5 %	43.0 %	133,100	44,574	57,220
Sweden	48.5	27.9 %	38.2 %	166,637	46,458	63,626
UK	42.0	16.7 %	28.6 %	1,046,251	175,038	299,497
Norway	–	–	–	54,428	0	0
Total		21.4 %	32.6 %	7,207,524	1,232,915	2,078,655

Source: Own calculation based on EU Buildings Database (Total floor area of dwellings 2014), Eurostat 2017 (population, energy consumption in the residential sector 2015).

shows that the savings sum up to a theoretical potential of 1.7 to 2.5 million TJ, which means percentage savings of energy used for space heating from 17.1 % at a 35 m²/cap to 28.8 % at a 30 m²/cap for the EU as a whole.

This potential would increase even more if electricity savings (e.g. from lighting) and energy savings of avoided new built homes and their building material would be considered. However, there are also aspects to discuss that can lower the potential.

FURTHER INDICATORS ON FLOOR AREA REDUCTION AND RELATED ENERGY SAVINGS

The potential of floor area reduction has to be reflected against some other indicators mentioned above:

- **Overcrowding and under-occupation.** Next to the floor area per person the indicator room per person is relevant for housing quality. In European statistics this indicator is used to assess the overcrowding and under-occupation rates of dwellings.⁶ From a sufficiency perspective a high overcrowding rate limits energy savings, as it is not compatible with the 'basic needs', and rather shows a need for more room and floor area. A high rate of under-occupation on the other hand indicates a high sufficiency potential. For the approach in the following chapter both rates are combined by subtracting the overcrowding rate from the under-occupation rate.⁷
- **Rate of unoccupied dwellings.** In European statistics dwellings are "... classified as being unoccupied if they are reserved for seasonal or secondary use (such as holiday homes) or if they are vacant (dwellings which may be for sale, for rent, for demolition, or simply lying empty and unused)" (Eurostat 2019 b). Within this paper it cannot be clarified in how far this definition is overlapping data on floor area per person (possibly also incorporating holiday homes) and which part of the dwellings is uninhabitable due to deficient condition of the building. Thus, for this first approach this indicator is not considered further within this paper. Although it is acknowledged that it might include a substantial energy sufficiency potential.
- **Indoor sanitary facilities.** Dwellings without indoor bath, shower and/or flushing toilet can be categorised as substandard. A country with a high proportion of the population lacking indoor sanitation, thus, has a lower potential to reduce per capita floor area. The dwellings rather need more room and floor area for indoor sanitary installation. Assuming that a low rate of lacking indoor sanitation hints to a general high standard including second or more baths it is considered as an indication for a sufficiency potential. More preferably data on secondary bathrooms, toilets, showers, etc. is not available.
- **Height of ceilings.** Next to the actual floor area, the height of rooms influences the perceived spaciousness (Stamps 2011) and hence the wish or need to move to a bigger or smaller

flat. High ceilings can offer possibilities for loft beds, storage, and other built-in elements and reduce the need for floor area. On the other hand, high rooms have more volume that needs to be heated and material to be built. Thus, from an energy saving perspective this rather seems to be an option for existing buildings with ceilings of three metres and more such as buildings from the turn of the 19th to the 20th century. Due to missing data in European statistics of ceiling heights and volumes of buildings (see Table 2), this indicator cannot be considered for further assessment in this paper.

- **Dwelling not comfortably warm in winter.** The size of a dwelling it not necessarily the reason for it not being comfortably warm. Nevertheless, this indicator is considered here as it is most probable that more energy has to be used to meet a basic need. Not comfortably warm dwellings might need improved efficiency first before they offer an energy saving sufficiency potential (e.g. in changed user behaviour). In southern countries, it is also possible that buildings do not have heating systems, and the installation would need space and floor area. In conclusion, a high share of this indicator is considered as reducing an energy sufficiency potential while a low rate is considered as a hint of a higher share of overheated dwellings and/or energy wasting heating behaviour.

Energy sufficiency potential in buildings in European countries

With the existing data it is not possible to tie up a quantitative assessment of these indicators to the results of reduced floor area in Table 5. The question if the people that are living in overcrowded dwellings are also lacking indoor sanitation and do not have it comfortably warm in winter (indicators for a reduced energy saving sufficiency potential) would be no more than a guess.

As the aim of the paper is rather to make sufficiency in buildings more tangible than to develop a quantitative measurement, it appears to be more expedient to chose a qualitative approach at this point. Therefore, the four remaining indicators on floor area reduction and related energy savings that we found data for (floor area per person in residential buildings, overcrowding and under-occupation rate, lack of indoor sanitary facilities, dwelling not comfortably warm in winter) are each rated from 0 (hardly any potential for sufficiency) to 4 (very high potential). The assigned ratings to the percentages are meant to cover the different ranges of indicators in the countries and can and should be discussed further (see chapter "Discussion"). Due to the limited length of this paper, Table 6 shows the exemplary results for 11 countries from different parts of Europe regarding the share of floor area reduction with a target of 35 m²/cap, the share of population living in under-occupied dwellings deducting the share living in overcrowded dwellings, the share of population having neither a bath, nor a shower, nor indoor flushing toilet in their household, the share of population reporting their dwelling not being comfortably warm in winter, and the suggested ratings per indicator from 0 to 4.

In a next step, for each country the ratings could be added and then divided by the number of indicators (four). For Belgium for example this would be:

6. It defines the adequate number of rooms including one room for the household, one per couple and one for each single person aged 18 or more. Two children of the same gender can share a room until the age of 17 but should have separated rooms from the age of 12 if they are of different gender (Eurostat 2014).

7. E.g. for Belgium: The share of population living in under-occupied dwellings in 2015 was 71.2 % and those living in overcrowded dwellings at 1.6 % (71.2 - 1.6 = 69.6; see Table 6).

Table 6. Experimental rating of the energy sufficiency potential in buildings in EU countries based on the indicators for floor space, under-occupation and over-crowding rates, indoor sanitary facilities, and comfort of warmth.

	Country	Potential	Rating	Country	Potential	Rating
	Theoretical potential of floor area decrease at 35 m ² /cap floor space			Population in under-occupied dwellings minus population in overcrowded dwellings		
	Belgium	8.3 %	1	Belgium	70 %	4
	Croatia	-6,1 %	0	Croatia	-32 %	0
	Germany	24.9 %	3	Germany	29 %	3
	Greece	34.9 %	3	Greece	-18 %	0
	Denmark	44.2 %	4	Denmark	37 %	3
	France	25.3 %	3	France	36 %	3
	Latvia	-1.3 %	0	Latvia	-30 %	0
	Luxembourg	31.5 %	3	Luxembourg	49 %	4
	Poland	-29.3 %	0	Poland	-31 %	0
	Romania	-93.8 %	0	Romania	-44 %	0
	Sweden	27.9 %	3	Sweden	32 %	3
0	very low potential	up to 0.0 %		very low potential	up to 0.0 %	
1	low potential	0.1 %–10 %		low potential	0.1 %–10 %	
2	average potential	10.1 %–20 %		average potential	10.1 %–20 %	
3	high potential	20.1 %–40 %		high potential	20.1 %–40 %	
4	very high potential	more than 40 %		very high potential	more than 40 %	
	Population having neither a bath, nor a shower, nor indoor flushing toilet in their household			Dwelling not comfortably warm during winter time		
	Belgium	0.2 %	3	Belgium	12.6 %	3
	Croatia	1.5 %	2	Croatia	7.8 %	3
	Germany	0,0 %*	4	Germany	3.6 %	4
	Greece	0.4 %	3	Greece	26.2 %	1
	Denmark	0.5 %	3	Denmark	12.9 %	2
	France	0.3 %	3	France	17.7 %	2
	Latvia	12.3 %	1	Latvia	20.3 %	2
	Luxembourg	0.0 %	4	Luxembourg	4.2 %	4
	Poland	2.6 %	2	Poland	15.5 %	2
	Romania	30.5 %	0	Romania	13.0 %	3
	Sweden	0.5 %*	3	Sweden	5.6 %	3
0	very low potential	more than 20 %		very low potential	more than 20 %	
1	low potential	10.1 %–20 %		low potential	10.1 %–20 %	
2	average potential	3.1 %–10 %		average potential	3.1 %–10 %	
3	high potential	0.6 %–3 %		high potential	0.6 %–3 %	
4	very high potential	< 0.5 %		very high potential	< 0.5 %	

* Estimate due to missing data. Source: Own calculation based on EU Buildings Database (Total floor area of dwellings 2014), Eurostat 2017 (population, comfort, occupation, and sanitation rates 2015).

- 8.3 % of floor area reduction with a target of 35 m²/cap corresponds to a '1'
- 70 % of the population living in under-occupied dwellings after deducting the share living in overcrowded dwellings corresponds to a '4'
- 0.2 % of the population having neither a bath, nor a shower, nor indoor flushing toilet in their household corresponds to a '3'
- 12.6 % of the population reporting their dwelling not being comfortably warm in winter corresponds to a '3'

which gives an overall rating of $(1+4+3+3) / 4 = 2.8$. Proceeding like this with the chosen European countries, the results are shown in Table 7. The mapping of the results in Figure 3 illustrates the high sufficiency potential in buildings in western and northern European countries, while it is lower in southern and eastern countries.

Discussion

This rather simple and experimental approach should be discussed and developed further. It needs more research to analyse the results of different classifications of indicators. It

Table 7. Qualitative estimate of an overall indicator of energy sufficiency potential in buildings in EU countries based on the indicators in Table 6.

Country	Score	Country	Score	Country	Score
Very high potential	3.1–4	Austria	3.0	Hungary	1.8
Luxembourg	3.8	Sweden	3.0	Low potential	0.9–1.6
Germany	3.5	United Kingdom	3.0	Estonia	1.5
Ireland	3.5	Belgium	2.8	Slovakia	1.5
Netherlands	3.5	France	2.8	Croatia	1.3
Denmark	3.3	Average potential	1.7–2.4	Bulgaria	1.0
Cyprus	3.3	Portugal	2.5	Poland	1.0
Malta	3.3	Italy	2.3	Very low potential	0–0.8
Finland	3.3	Czech Republic	2.0	Latvia	0.8
High potential	2.5–3.0	Slovenia	2.0	Lithuania	0.8
Spain	3.0	Greece	1.8	Romania	0.8

Source: Own calculation based on EU Buildings Database (Total floor area of dwellings 2014), Eurostat 2017 (population, comfort, occupation, and sanitation rates 2015).

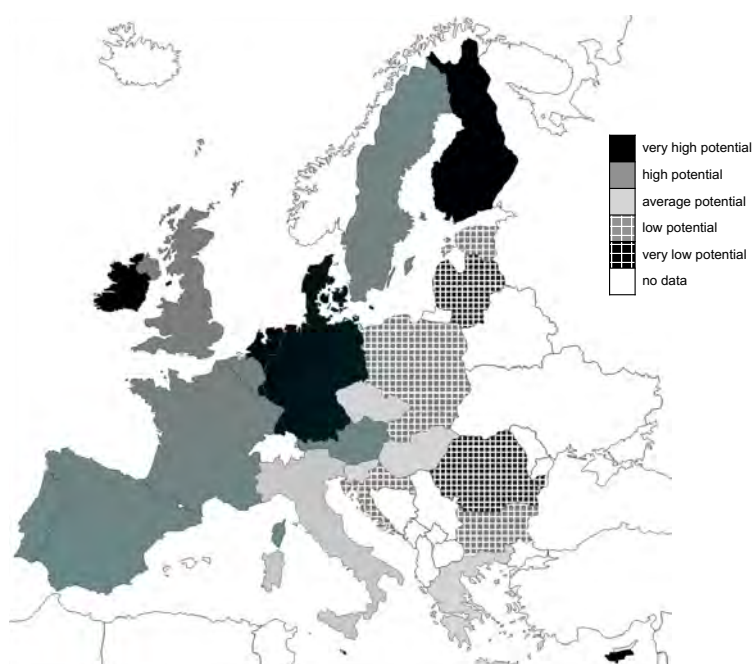


Figure 3. Mapping of the energy sufficiency potential in residential buildings in European countries. Source: Own illustration based on Bierwirth and Thomas (tbp).

might be that a different approach (e.g. non-equal weighing of indicators) or even completely different indicators have a higher impact on the assessment of energy sufficiency and its saving potential in buildings and, thus, lead to different results. Furthermore, the quantification of other indicators is needed to estimate the full potential of energy sufficiency in buildings, e.g. including energy used for resources and building components.

In a next step, it would be interesting to match the results with the structure of heating systems in residential buildings to translate the energy savings to reductions in CO₂ emissions. But, as said before, the aim of the paper is rather an attempt to make the potential of energy sufficiency in buildings more tangible than a final estimation of savings. It can be seen as a first experimental approach and as such the paper seeks to foster the discussion on integrating sufficiency into energy and climate studies and scenarios, identify lacks of data to make sufficiency more applicable for research, and contribute to the development of energy sufficiency policies.

Conclusion

Even though the estimation and quantification of an energy sufficiency potential in buildings is at a very early stage, the results indicate a high potential. This first rough approximation, however, should be considered when discussing energy sufficiency policy at European level, keeping in mind that the definition mentioned above refers to a maximum as well as to minimum limits. Thus, European sufficiency policy has to cover both: supporting adequate housing in countries where basic needs are not met yet and foster energy savings from sufficiency in countries with a high potential.

In both areas it is worth to develop sufficiency research further and support assessments, modelling, policy development, and experiments in the area of sufficiency in buildings. The question of sufficiency policies as a complementary strategy to or integrated with efficiency policies could be of specific interest. Can energy sufficiency requirements for buildings, products, and national implementation policies be included e.g. in the Energy Efficiency Directive, the Energy Performance of Buildings Directive (EPBD), and the Ecodesign Directive on products? And how can policy be designed to foster sufficiency in both directions: meeting basic needs and environmental limits?

The concept paper on sufficiency in buildings by Bierwirth and Thomas (tbp) discusses a wide range of instruments addressing energy sufficiency in the 'space' area, such as

- municipal living space agencies,
- financial incentives for alternative concepts of housing with smaller per capita area and dwelling space,
- communal living and co-housing,
- the development of an energy-sufficient building infrastructure,
- energy pricing instruments, and
- a cap on average dwelling floor area per person as an overarching instrument,

as well as policy instruments to integrate energy sufficiency and efficiency in the areas of design and construction, equipment, and use.

These instruments need to be tested and – where implemented already – assessed. Though the results of sufficiency research so far are rather preliminary, they indicate that it is worth to develop and implement sufficiency in buildings as a contribution to energy and climate targets.

References

- Bierwirth, A. (2015): Almost best friends: sufficiency and efficiency. Can sufficiency maximise efficiency gains in buildings? Presentation at eceee summer study 2015. Download at: https://www.eceee.org/library/conference_proceedings/eceee_Summer_Studies/2015/1-foundations-of-future-energy-policy/almost-best-friends-sufficiency-and-efficiency-can-sufficiency-maximise-efficiency-gains-in-buildings/2015/1-081-15_Bierwirth_pre.pdf/ (accessed: 2019-02-18).
- Bierwirth, A.; Thomas, S. (tbp): Energy sufficiency in buildings. Concept paper. Stockholm, Sweden: eceee.
- Brischke, L.-A.; Lehmann, F.; Leuser, L.; Thomas, S.; Baedeker, C. (2015a): Energy sufficiency in private households enabled by adequate appliances. In: eceee summer study proceedings 2015, Paper No. 7-294-15.
- Brischke, L.-A., Leuser, L., Thomas, S., Spitzner, M., Thema, J., Ekhardt, F., Kopatz, M., Duscha, M. (2015b): Energiesuffizienz – AP 1 Rahmenanalyse. Heidelberg, Germany.
- Bundesministerium des Innern, für Bau und Heimat (BMI) (ed.) (2017): Ökobaudat. Informationsportal nachhaltiges Bauen. <https://www.oekobaudat.de/service/downloads.html> (accessed: 2019-01-13).
- Darby, S.; Fawcett, T. (2018): Energy sufficiency: an introduction. Concept paper. Stockholm, Sweden: eceee.
- Delzendeh, E.; Wu, S.; Lee, A.; Zhou, Y. (2017): The impact of occupants' behaviours on building energy analysis: A research review. In: Renewable and Sustainable Energy Reviews, Volume 80, pp. 1061–1071.
- Destatis – Statistisches Bundesamt: Bevölkerung (2019): Deutschland, Stichtag. https://www-genesis.destatis.de/genesis/online/data;sid=58504535C48D7706F5DB21312BAD23E0.GO_1_3?operation=abruftabelleBearbeiten&levelindex=2&levelid=1547403852812&auswahloperation=abruftabelleAuspraegungAuswaehlen&auswahlverzeichnis=ordnungsstruktur&auswahlziel=werteabruf&selectionname=12411-0001&auswahltext=&werteabruf=Werteabruf (accessed: 2019-01-13).
- Doka, G. (2000): Ökoinventar der Entsorgungsprozesse von Baumaterialien. Grundlagen zur Integration der Entsorgung in Ökobilanzen von Gebäuden. Zurich, Switzerland.
- Elgin, D.; Mitchell, A. (1977): Voluntary simplicity. In: Strategy & Leadership 5, 13–15.
- Eurostat (2019 a): Database: <https://ec.europa.eu/eurostat/data/database> (accessed: 2019-02-22).
- Eurostat (2019 b): People in the EU – statistics on housing conditions. https://ec.europa.eu/eurostat/statistics-explained/index.php/People_in_the_EU_-_statistics_on_

- housing_conditions#Housing_characteristics:_unoccupied_dwellings (accessed: 2019-01-20).
- Eurostat (2018): EU Buildings Database: <https://ec.europa.eu/energy/en/eu-buildings-database> (accessed: 2018-11-22).
- Eurostat (2017): Population, energy consumption in the residential sector 2015.
- Eurostat (2014): Glossary: Overcrowding rate. https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Overcrowding_rate (accessed: 219-02-20).
- Fischer C., Blanck R., Brohmann B., Cludius J., Förster H., Heyen D. A., Hünecke K., Keimeyer F., Kenkmann T., Schleicher T., Schumacher K., Wolff F., Beznoska M., Steiner V., Gruber E., Holländer E., Roser A., Schakib-Ekbatan K. (2016): Konzept zur absoluten Verminderung des Energiebedarfs: Potenziale, Rahmenbedingungen und Instrumente zur Erreichung der Energieverbrauchsziele des Energiekonzepts. Dessau-Roßlau, Germany.
- Günther, J.; Lehmann, H.; Lorenz, U.; Purr, K. (2017): Den Weg zu einem treibhausgasneutralen Deutschland ressourcenschonend gestalten. Dessau-Roßlau, Germany.
- Meadows, D. H. (1972): The limits to growth. Universe Books, New York, USA.
- Ministerium des Inneren des Landes Nordrhein-Westfalen (IM NRW) (2019). Wohnraumnutzungsbestimmungen. https://recht.nrw.de/lmi/owa/br_text_anzeigen?v_id=100000000000000000462 (accessed 2019-01-13).
- Morgan, M.; Cruickshank, H. (2014): Quantifying the extent of space shortages: English dwellings. In: Building Research & Information, UK.
- négaWatt (2017): Scénario négaWatt 2017-20150. Dossier de synthèse. Valence, France.
- Pfäffli, K. (2012): Grundlagen zu einem Suffizienzpfad Energie – Das Beispiel Wohnen. Zurich, Switzerland.
- Pyrko, J.; Darby, S. (2011): Conditions of energy efficient behaviour – a comparative study between Sweden and the UK. In: Energy Efficiency, Volume 4, Issue 3, pp 393–408.
- Raworth, K. (2012): A safe and just space for humanity. Can we live within the doughnut? Oxfam Discussion Papers.
- Rockström, J.; Steffen, W., Noone, K., Persson, Å., Chapin, F. S.; Lambin, E.; Lenton, T. M.; Scheffer, M.; Folke, C.; Schellnhuber, H.; Nykvist, B.; De Wit, C.A.; Hughes, T.; van der Leeuw, S.; Rodhe, H.; Sörlin, S.; Snyder, P. K.; Costanza, R.; Svedin, U.; Falkenmark, M.; Karlberg, L.; Corell, R. W.; Fabry, V. J.; Hansen, J.; Walker, B.; Liverman, D.; Richardson, K.; Crutzen, P.; Folev. J. (2009): Planetary boundaries: exploring the safe operating space for humanity. In: Ecology and Society 14(2): 32. Available at: <http://www.ecologyandsociety.org/vol14/iss2/art32/> (accessed: 2019-01-19).
- Samadi S., Gröne M., Schneidewind U., Luhmann H., Venjakob J., Best B. (2017): Sufficiency in energy scenario studies: Taking the potential benefits of lifestyle changes into account. In: Technological Forecasting & Social Change, Volume 124, pp. 126–134.
- Schmitt, C., Leuser, L. Brischke, L.-A., Duscha, M., Jacobson S. (2015): Suffizienz-Maßnahmen und Politiken in kommunalen Klimaschutzkonzepten und Masterplänen – ein Überblick. Heidelberg, Berlin, Germany.
- Schneidewind, U.; A. Zahrnt (2013): The Politics of Sufficiency. Making it easier to live the Good Life. Oekom, Munich, Germany.
- Stamps, A. (2011): Effects of Area, Height, Elongation, and Color on Perceived Spaciousness. In: Environment and Behaviour, Volume 43, issue: 2, pp 252– 273.
- Thema, J. (2015): Kriteriengestützte Analyse von Optionen energiesuffizienten Handels im Sektor Bauen/Wohnen. Wuppertal: Wuppertal Institut für Klima, Umwelt, Energie gGmbH.
- Thomas, S., Brischke, L.-A., Thema, J., Kopatz, M. (2015): Energy Sufficiency Policy: An evolution of energy efficiency policy or radically new approaches? In: eceee summer study proceedings 2015, Paper No. 1-060-15.
- Thomas, S.; Brischke, L.-A.; Thema, J.; Leuser, L.; Kopatz, M.; Spitzner, M. (2018): Energy sufficiency policy for residential electricity use and per-capita dwelling size. In: Energy Efficiency, 2018. <https://link.springer.com/article/10.1007%2Fs12053-018-9727-4> (accessed 2019-01-11).
- United Nations (2018): The Sustainable Development Goals Report 2018. New York, USA.
- Zell-Ziegler C., Förster H. (2018): Mit Suffizienz mehr Klimaschutz modellieren. Dessau-Roßlau, Germany.
- ## Acknowledgements
- This paper is an extended extract of the methodical part of the concept paper on sufficiency in buildings by Bierwirth and Thomas (tbp). The work is part of the eceee's energy sufficiency project funded by the KR Foundation. The authors would like to thank eceee and the KR Foundation for their support of sufficiency research and policy making. And they would like to encourage their readers to find out more about the topic at www.energysufficiency.org.

Acknowledgements

This paper is an extended extract of the methodical part of the concept paper on sufficiency in buildings by Bierwirth and Thomas (tbp). The work is part of the eceee's energy sufficiency project funded by the KR Foundation. The authors would like to thank eceee and the KR Foundation for their support of sufficiency research and policy making. And they would like to encourage their readers to find out more about the topic at www.energysufficiency.org.